Components in Wireless Technologies

Course Introduction

Sander Bronckers

Today

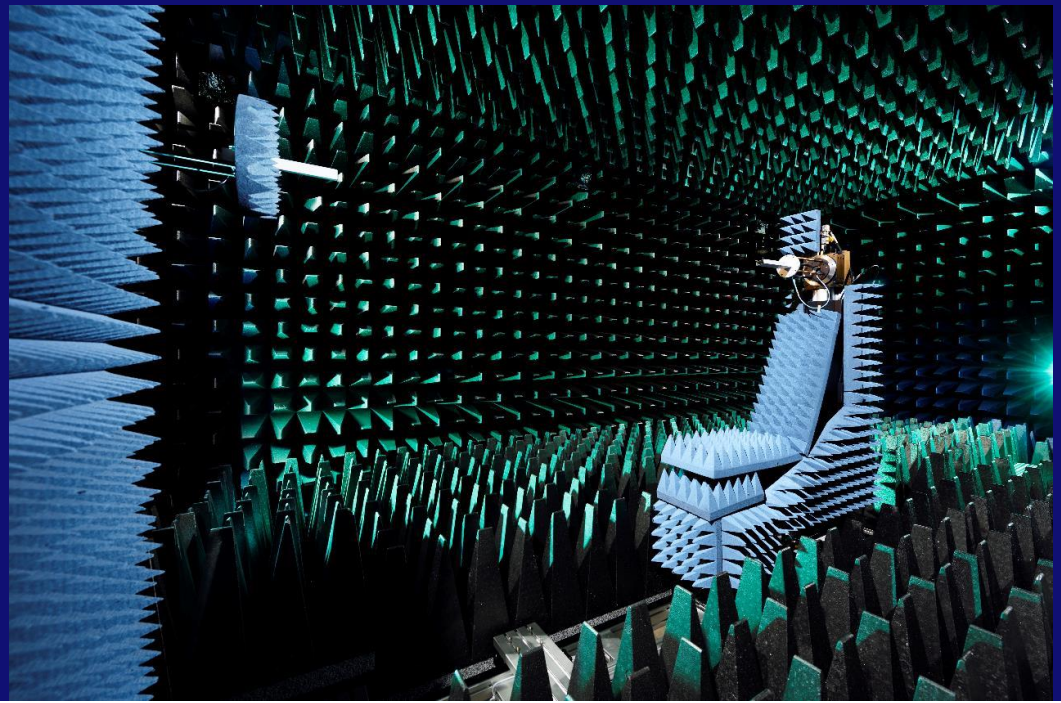
First two hours:

- About this Course
- Overview of a Wireless system

Second two hours:

- Transmission line theory (module 1)

About this Course



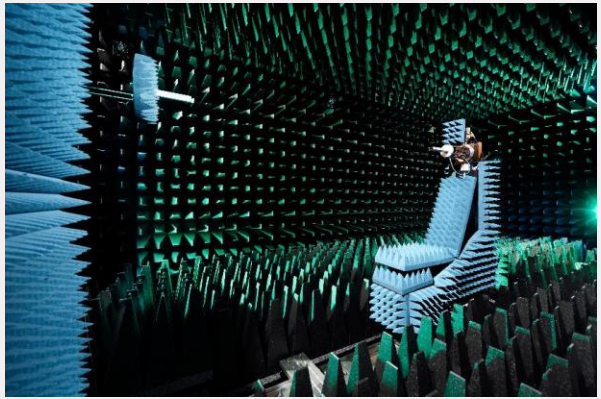
The Team

Lecturers

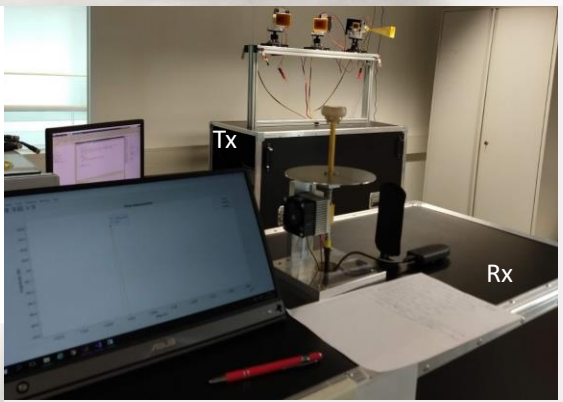
- Dr. Sander Bronckers (me) – EM, responsible lecturer. L.A.Bronckers@tue.nl
- Dr. Gabriele Federico - EM. g.federico@tue.nl
- Dr. Ulf Johannsen – EM. U.Johannsen@tue.nl
- Dr. Vojkan Vidojkovic – IC. V.Vidojkovic@tue.nl
- Dr. Ing. Ad Reniers – EM. A.Reniers@tue.nl
- Dr. ing. Rainier van Dommele – IC. A.R.v.Dommele@tue.nl

... + lots of help from PhD students!

Some cool measurement Systems



- Metrology for Antennas and Wireless Systems



Embedding in the Curriculum

- Part of the *Connected World* package
- Courses:

Course code	Course name	Scheduled (Quarter/Slot)
5XTA0	Telecommunication systems	Quarter 4/ Slot B
5XTB0	Photonics	Quarter 2/ Slot E
5XTC0	Components in wireless technologies	Quarter 3/ Slot E

Prior knowledge

- Electromagnetics I + II
- (Electronic) circuits
- Fourier transformation (Time-harmonic analysis)

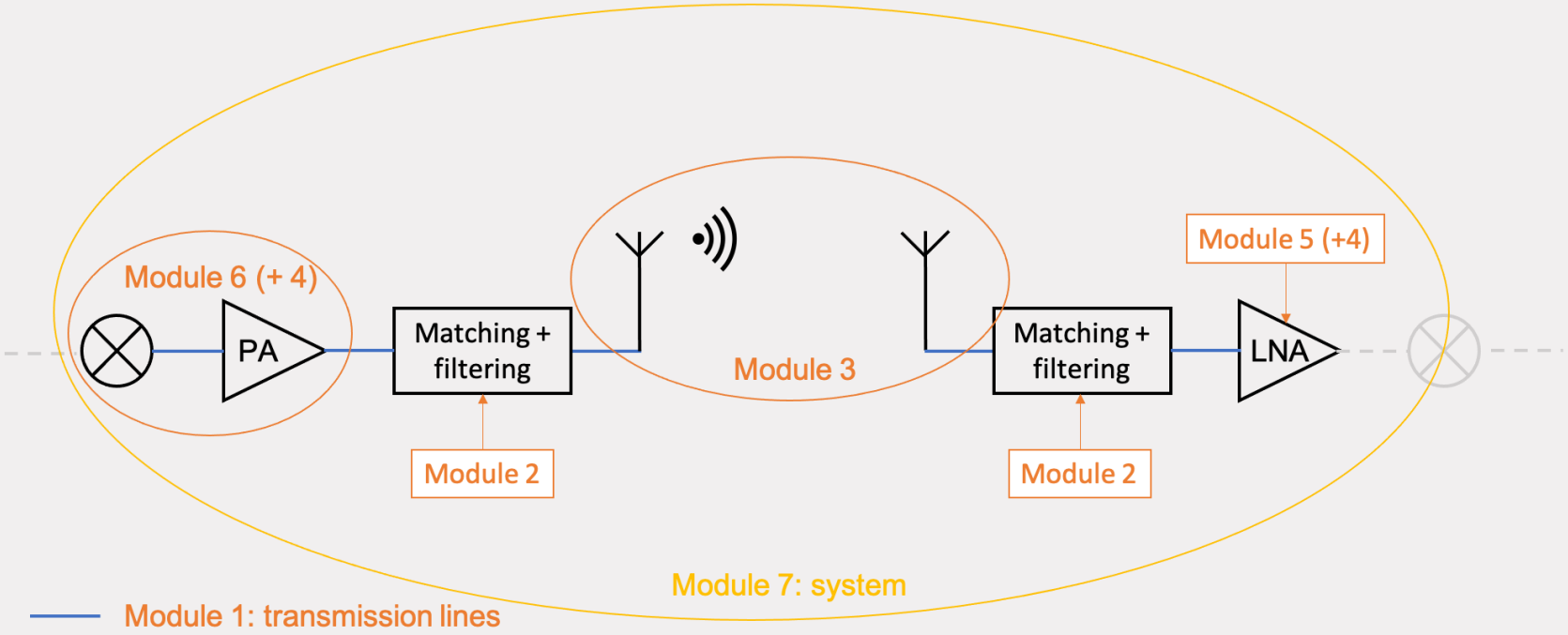
Also useful:

- Introduction Telecom/Telecommunication systems

What will you learn?

- The major aspects of the analog part of a wireless system:
  - Transmission lines
  - Passive microwave networks
  - Introduction to antennas
  - Introduction to microwave amplifiers
  - Wireless systems: Link-budget analysis and component specification
- All from three intertwined points of view:
  - Lectures
  - Exercise sessions
  - Labs

Modules - Overview



Modules – Content

- Modules each take a look at one particular aspect or component
- Should be followed sequentially!
- Each module contains:
  - Lecture(s)
  - Exercise class(es)
  - Hands-on lab(s): put things into practice!

Planning 2024-2025…

- STUDY GUIDE!
- Week of Mar. 3: Carnaval Break
- Mar. 13: **Intermediate test**
- For the rest: see study guide!
  - Always leading document
  - Adapted to the 7-week quartile

Module	Session Content		When (date, hours)	Where	Lecturer	Instructors
Intro	Lecture:	Course overview	Feb 11, 5+6	Atlas 6.225	Bronckers	-
Module 1: Transmission lines	Lecture:	Transmission line theory	Feb 11, 7+8	Atlas 6.225	Bronckers	-
	Exercises:	Transmission lines	Feb 13, 1+2	Atlas -1.822	Bronckers	Akmal, Wubalem
	Lab:	QUCS intro	Feb 13, 3+4	Atlas -1.822	Dommele, Vidojkovic	
Module 2: Passive microwave networks	Lecture:	Passives & Smith chart	Feb 18, 5+6	Atlas 6.225	Bronckers	-
	Exercises:	Passives & Smith chart	Feb 18, 7+8	Atlas 6.225	Bronckers	Akmal, Wubalem
	Lecture	Measurement Uncertainty	Feb 20, 1	Atlas -1.822	Reniers	-
	Lab kit handouts during the following lab:					
	Lab:	VNA measurements of passives	Feb 20, 2-4	Atlas -1.822	Federico	Akmal, Wubalem

Lectures

- On-campus only
- Some old recordings are available, but content might not always be the same
- Lecture assumed prior knowledge in module’s exercise session(s) and lab(s)

Exercise sessions

- Prepare by making sure you're familiar with the module's lecture contents

Labs

- Mixture of simulations and measurements:
  - QUCS
  - nanoVNA + antennas, passive structures, amplifier, etc.
  - Personal kit, you are responsible for it!
  - ALWAYS bring your laptop.
- Groups of max. 3 students
  - You do all your assignments yourself
  - Share all results in your group and compare – are they different? Why?
  - Discuss tips/tricks!

Lab kits

- You will receive a lab kit during the Feb. 20 lab
- Form to sign
- YOUR kit is YOUR responsibility! – you need to return it properly!
  - This makes your lab exam grade valid

Grading

- 50%: Final written exam
  - On-campus
  - Minimum grade to pass course is 5.0
- 30%: Lab (oral) exams – next slide
- 20%: Intermediate written exam
  - Written test about all course content up to and including week 3
  - On-campus, Mar. 13.

Lab exams

- ‘Carousel’ model
- 8 minutes with each panel member // topic, then ‘rotate’
- For each topic, short presentation and discussion
- See study guide for details

Material

- Lecture slides (canvas)
- Materials and software for labs (provided)

Optional:

- Video lectures from earlier years (on canvas in YuJa)
- Books for more background material (optional):
  - A.B. Smolder et al., Modern Antennas and Microwave Circuits. Free download via https://arxiv.org/abs/1911.08484
  - D.M. Pozar, Microwave Engineering, John Wiley & Sons, Inc.
  - C.A. Balanis, Antenna Theory – Analysis and Design, John Wiley & Sons, Inc.
  - W. Hayt, Engineering Electromagnetics, (Chapter 10), McGraw-Hill.
  - B. Razavi, RF Microelectronics, Prentice Hall
  - G. Gonzalez, Microwave Transistor Amplifiers, Prentice-Hall.

Canvas

- Study guide is available here
  - Leading document, also for planning
  - Please check!
  - In case there are major updates (not expected), we will notify you
- Sign up for a team (max. 3 people) before Thursday 13/02!
  - Under ‘people’

Overview of a Wireless System

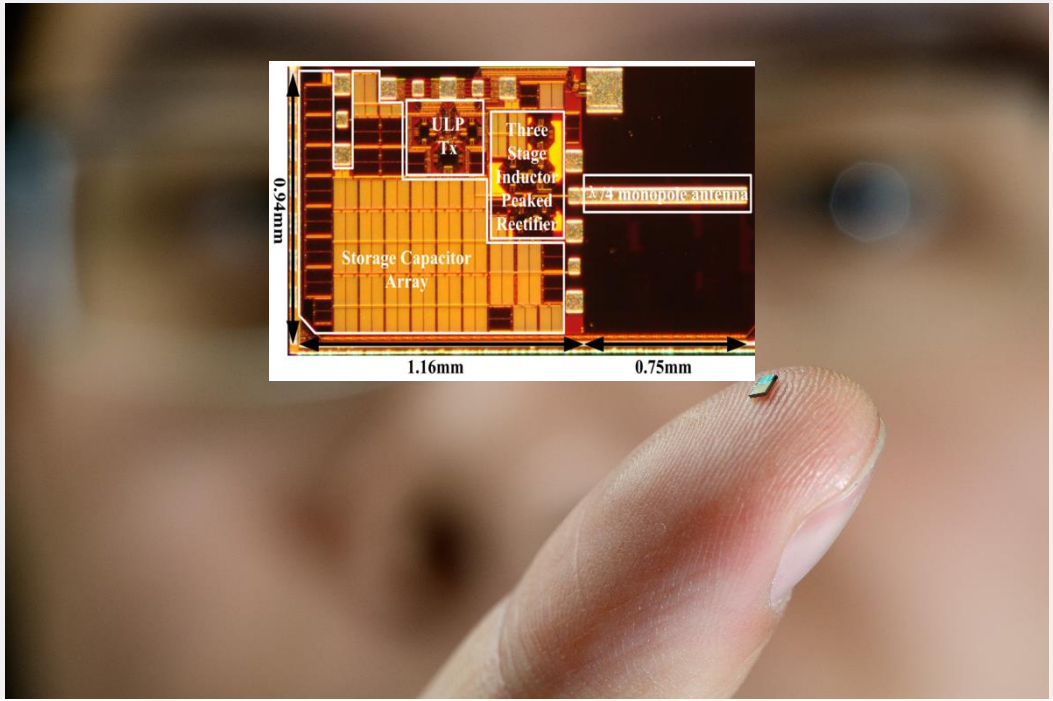
- **Application Examples**
- What goes into a Wireless System?

‘Microwave Engineering’

- We’ll be dealing with RF/Microwave components
  - Do NOT confuse with heating your food!
- What is the difference between analogue and RF/Microwave signals?
  - RF/Microwave signals are a special case of analogue signals (actually the other way around!)
  - We have to use RF/Microwave techniques whenever the considered structure is electrically large ($>\lambda/10$).

An electrically large structure...

… Another electrically large structure!



Where do we find such cases and systems?

... Everywhere!

Wireless communications

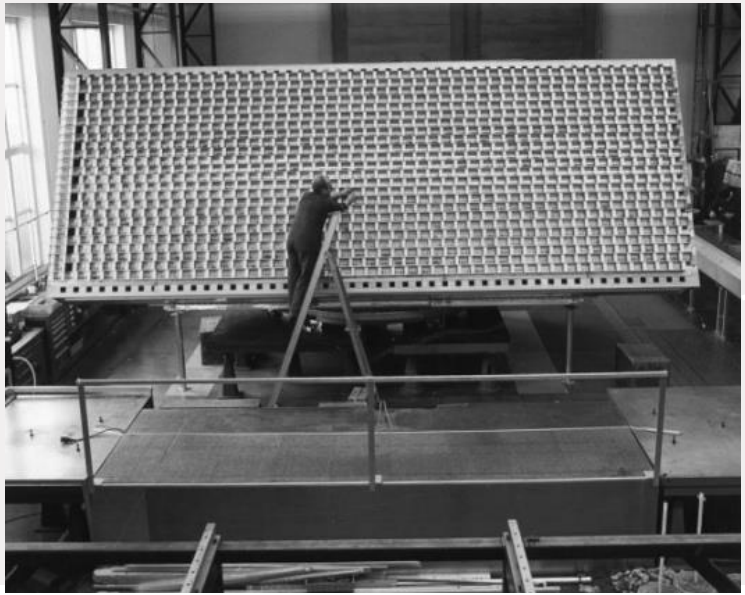
- All wireless systems! Smartphones, tablets, laptops, …
  - WiFi
  - 1G, … 5G (and beyond)
  - Bluetooth
  - Devices are PACKED with this technology

    … And this is only increasing

And of course, practically all IoT devices!

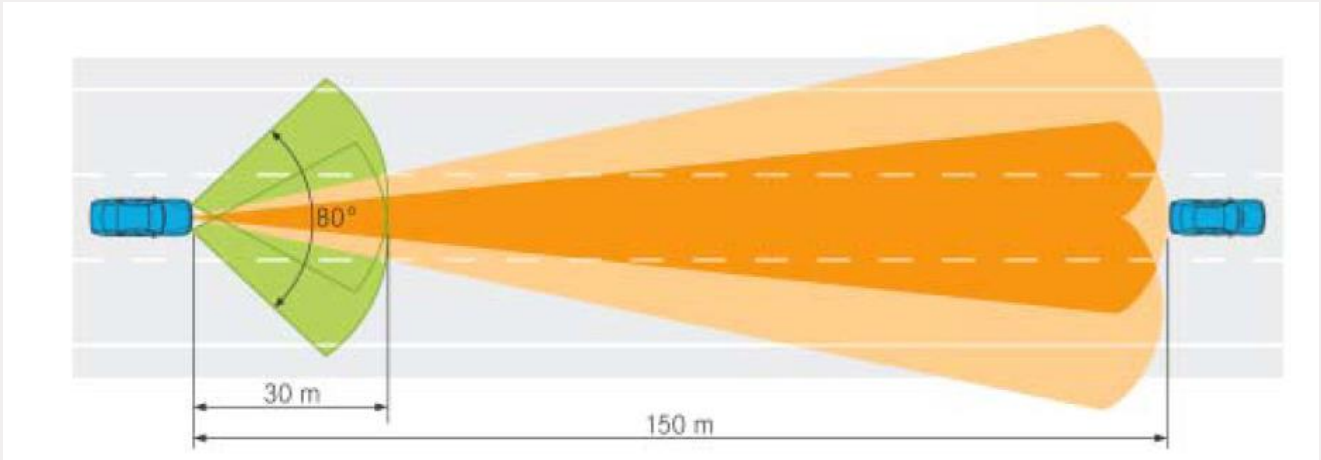
Figures: part of the wireless systems in a smartphone (https://www.ifixit.com/Teardown/iPhone+12+Pro+Max+Teardown/138640)

L-band radar



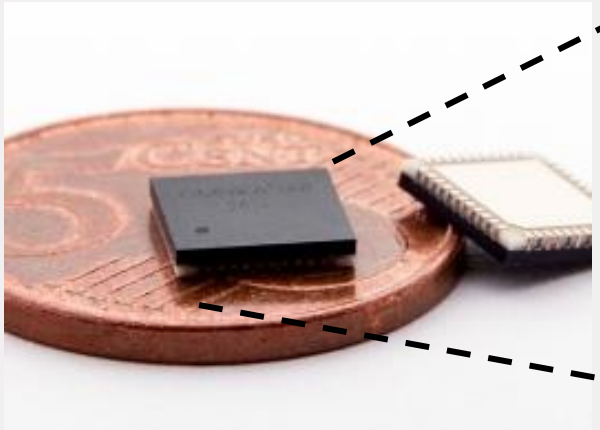
Ref: M.C. Van Beurden, A.B. Smolders, IEEE Trans. AP, 2002, pp.1266-1273

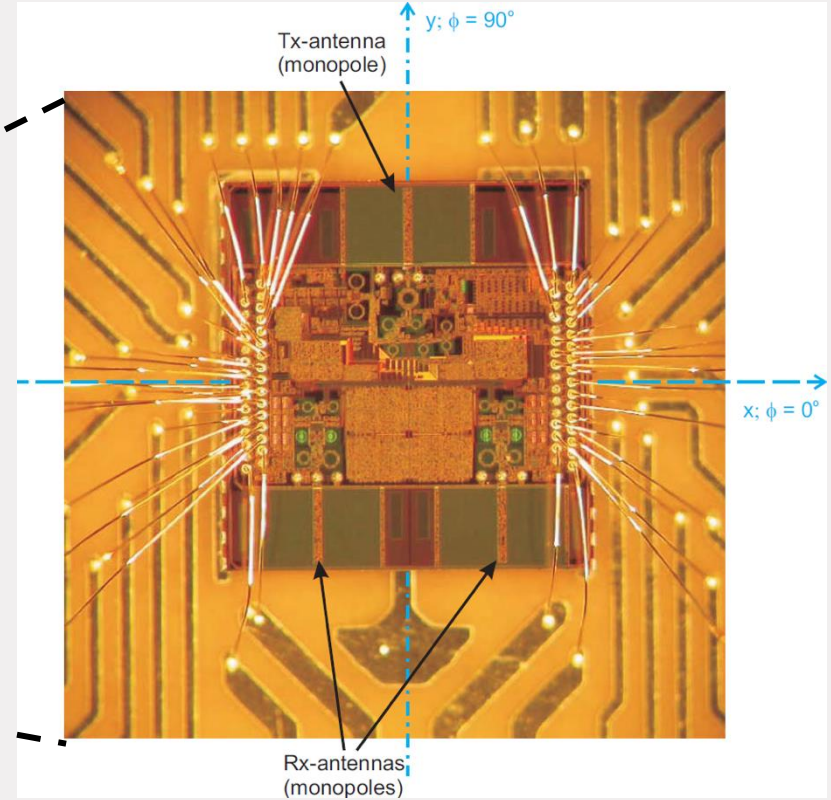
Car radar



Single-chip 60 GHz radar

TU/e + omniradar





Single-chip 60 GHz radar

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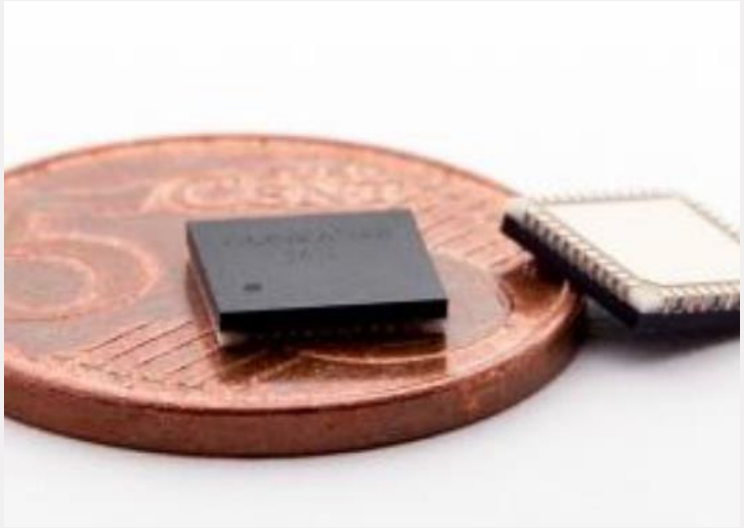
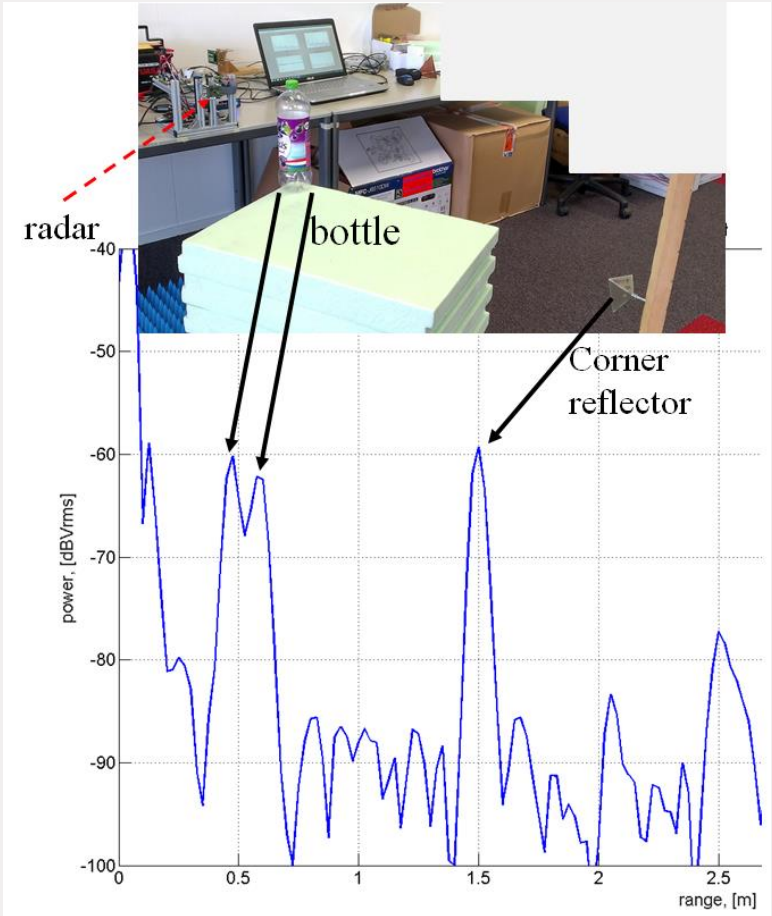
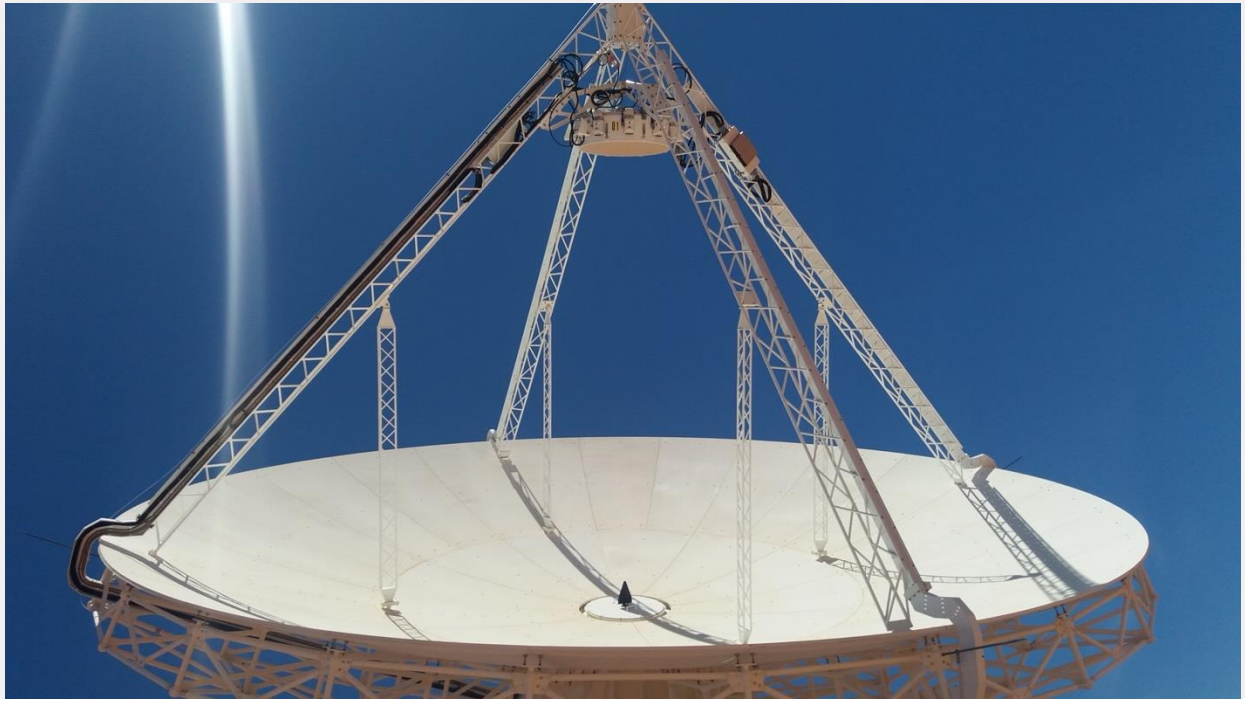


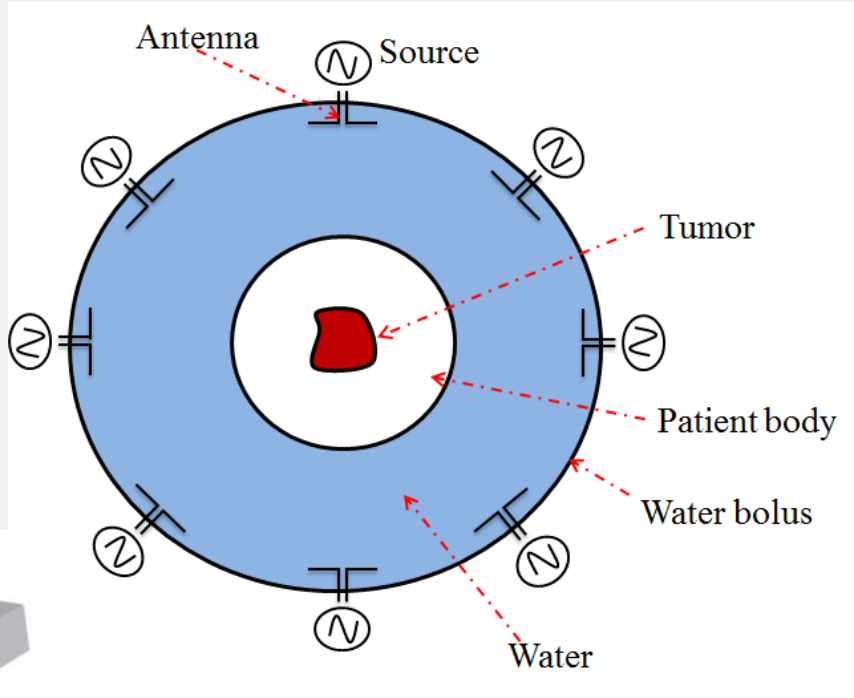


Radio astronomy



Radio astronomy - array

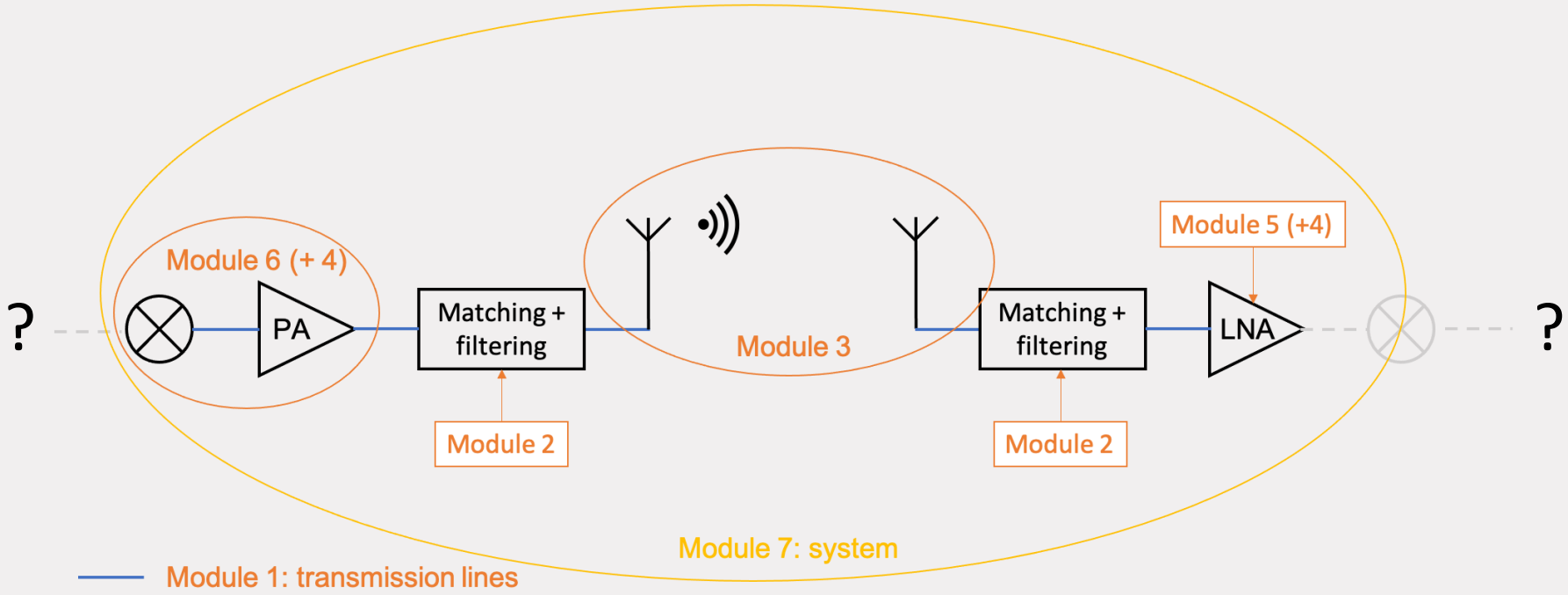
Hyperthermia



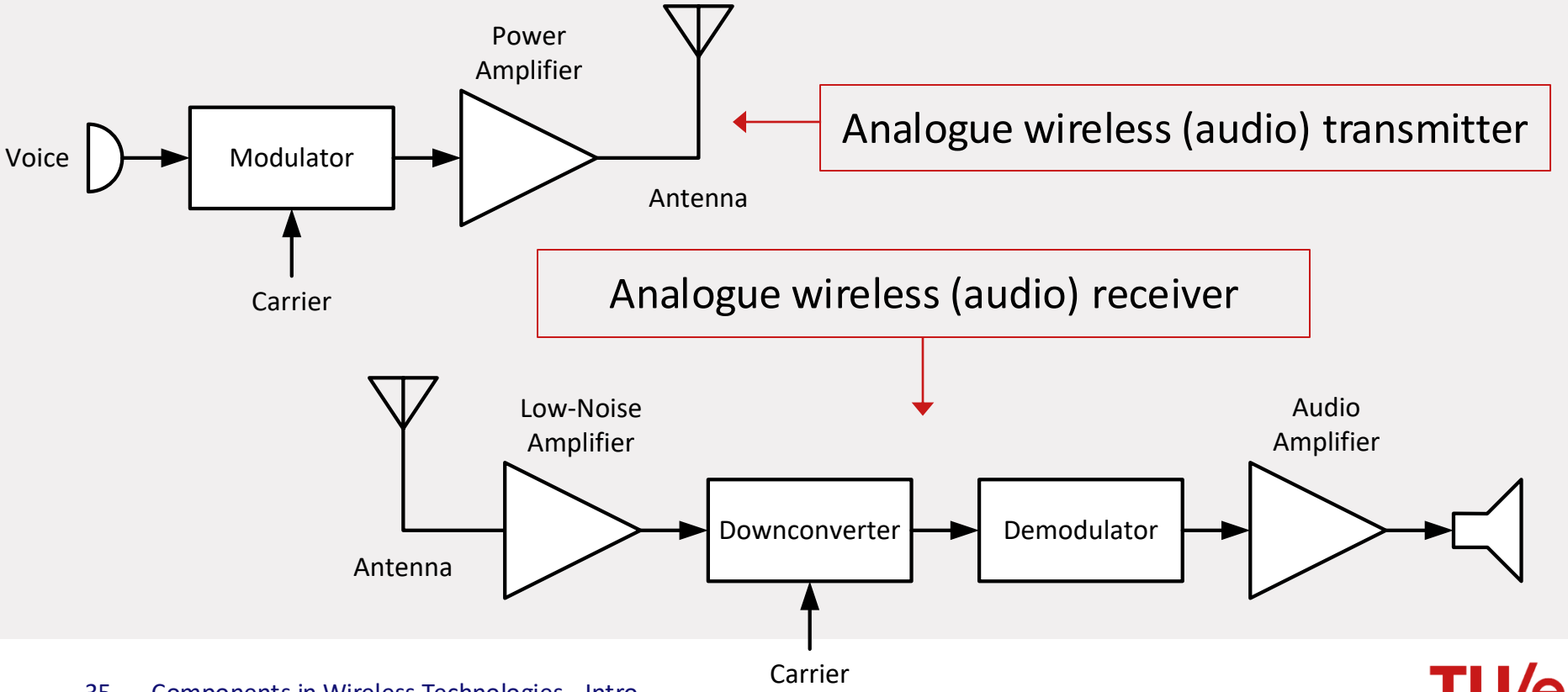
Overview of a Wireless System

- Application Examples
- **What goes into a Wireless System?**

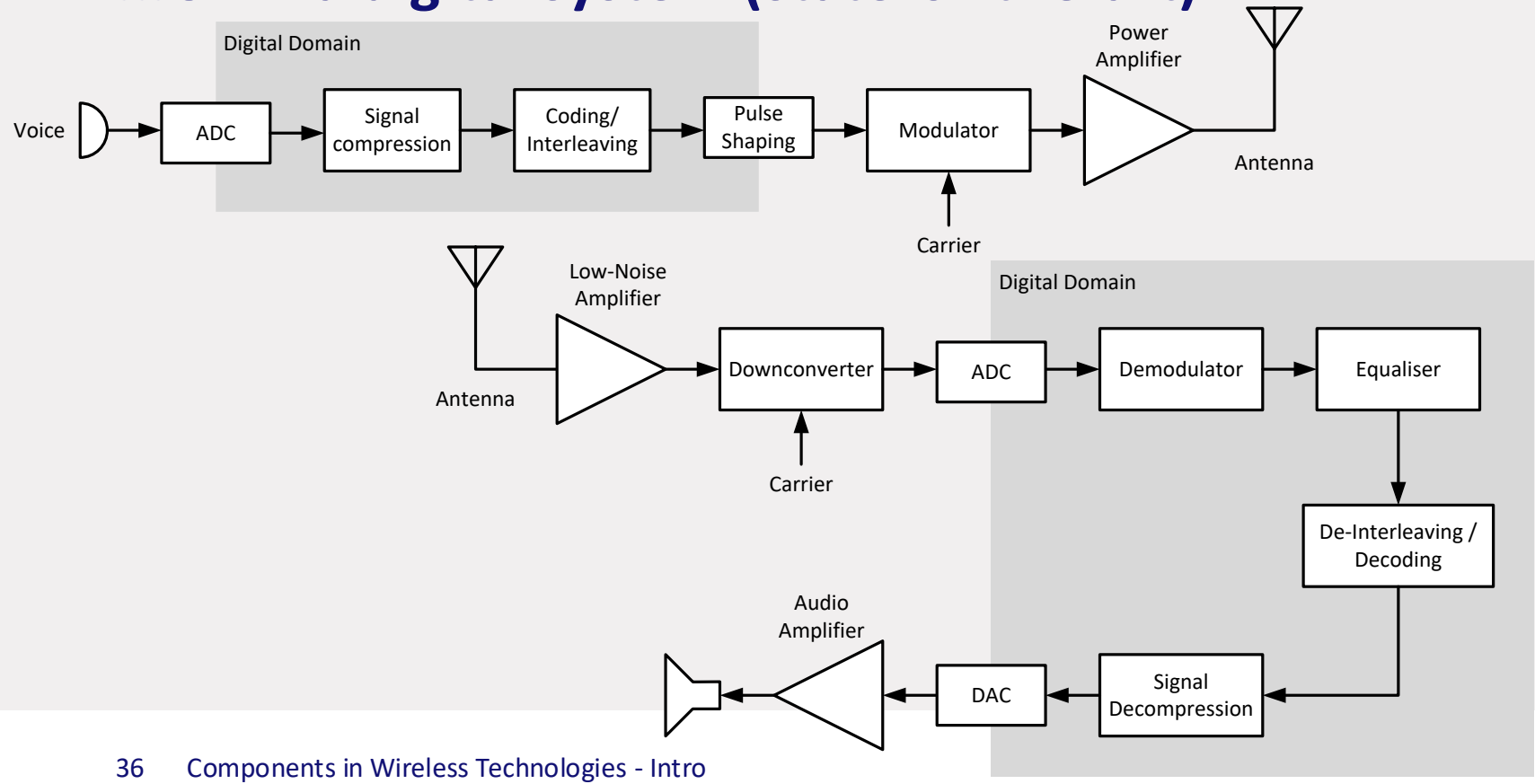
Back to our overview...



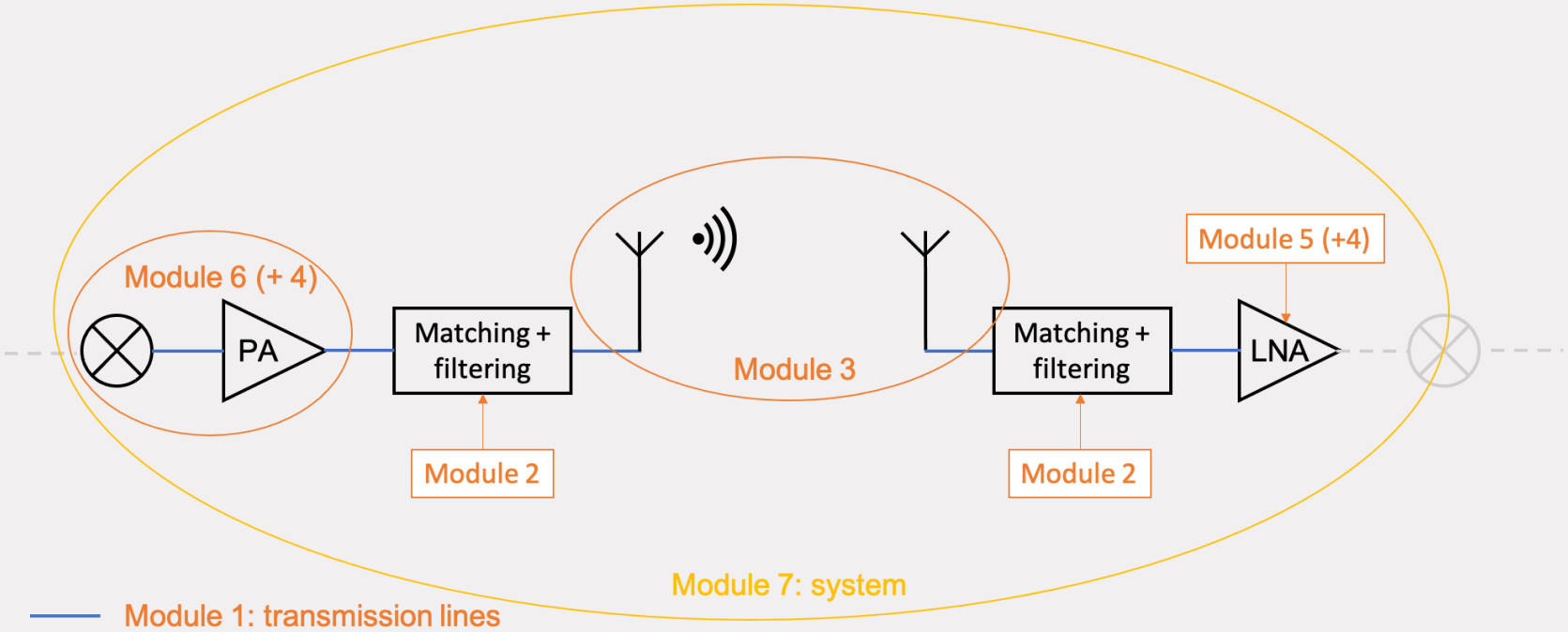
...In an analogue system (rather old-fashioned...)



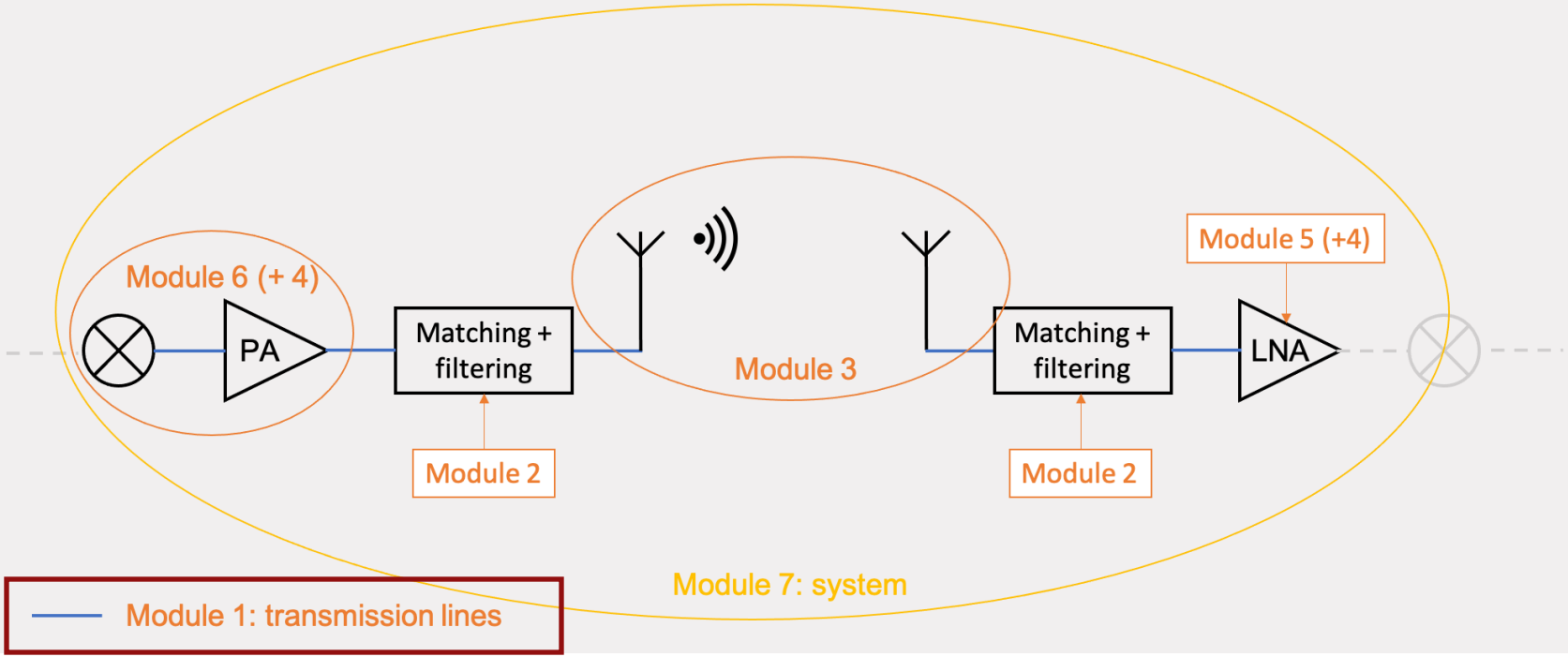
...Or in a digital system (state-of-the-art)



This course: focus on the RF parts



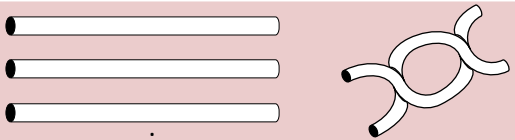
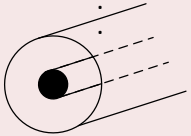
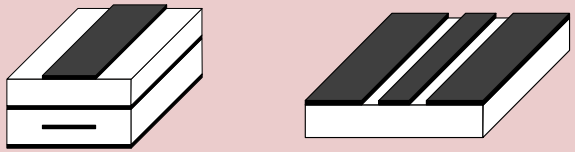
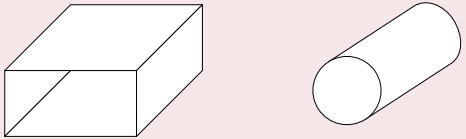
Module 1: transmission lines



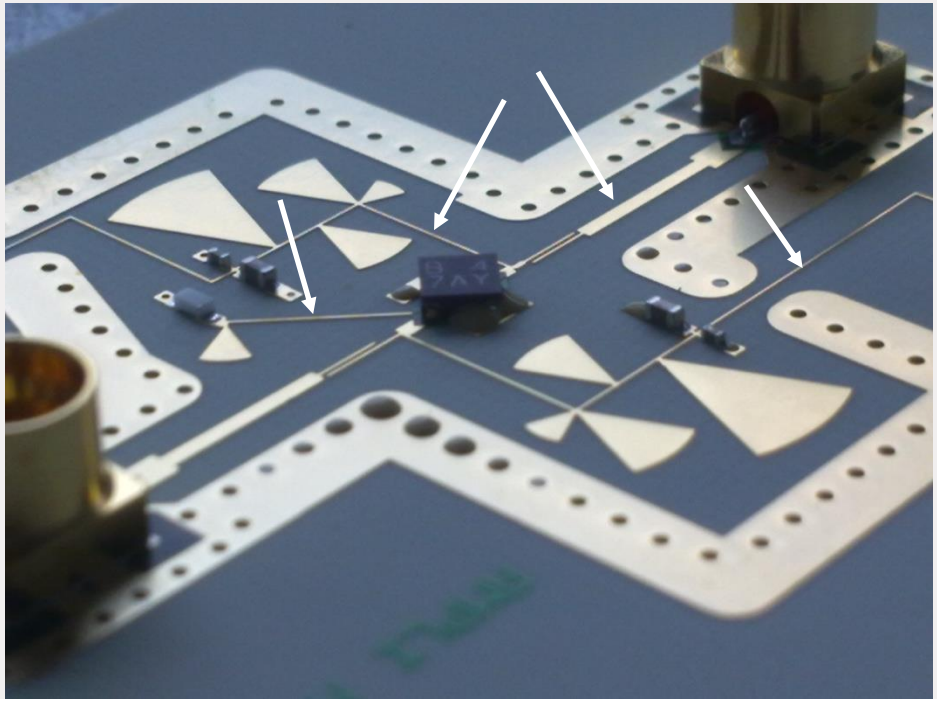
Module 1: transmission lines

- Just a wire? → Not if structure is electrically large!
- We need something to connect things together that:
  - Isn’t very lossy
  - Doesn’t radiate too much
  - Is impedance matched

Module 1: transmission lines – some examples

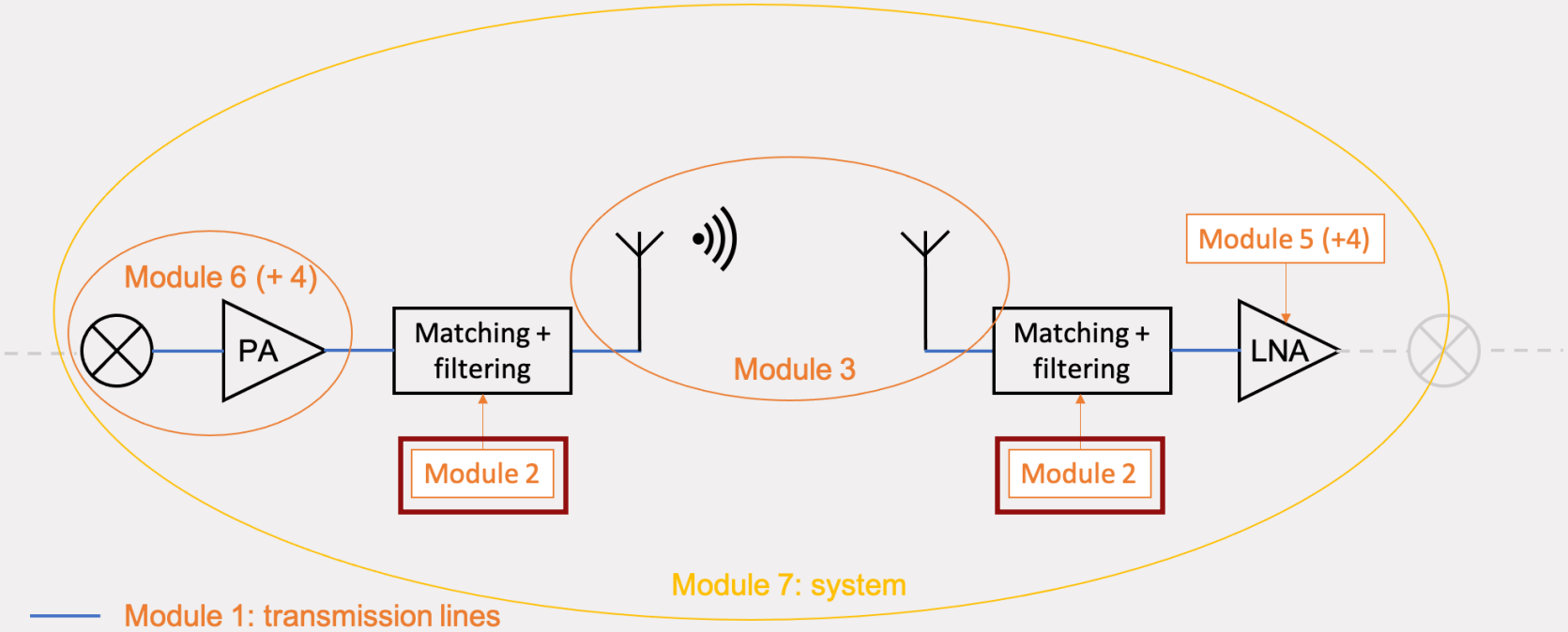
Examples of transmission line	Schematic view	Field mode
Parallel wires and twisted pair		TEM
Coaxial		TEM
Micro-/Strip and coplanar waveguide		Quasi-TEM
Hollow waveguides		Non-TEM

24 GHz LNA – transmission lines



Can you find more?

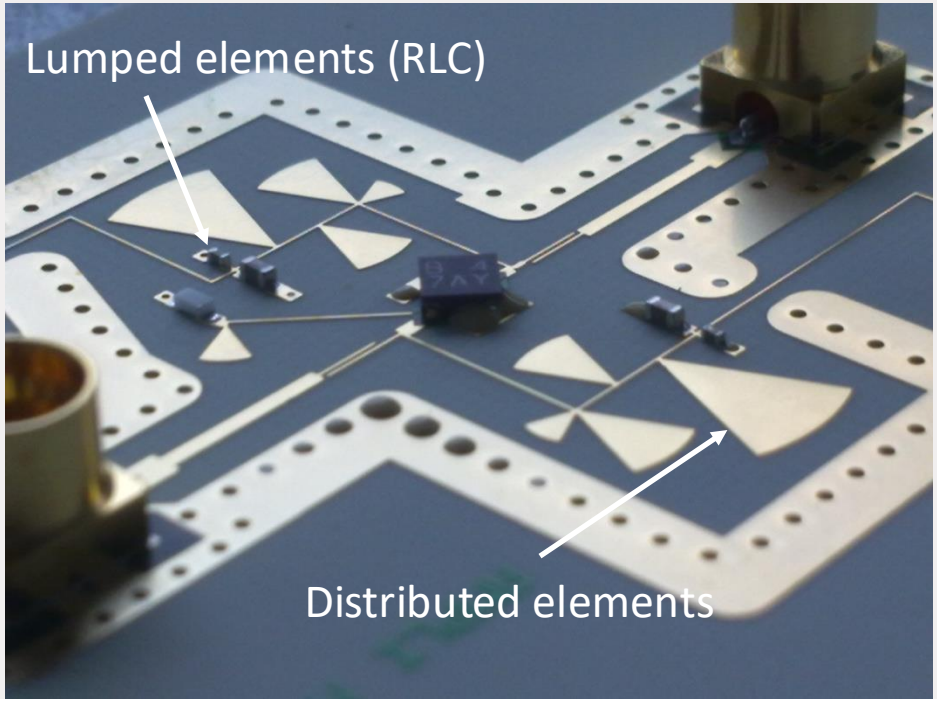
Module 2: passive microwave networks



Module 2: Passive microwave networks

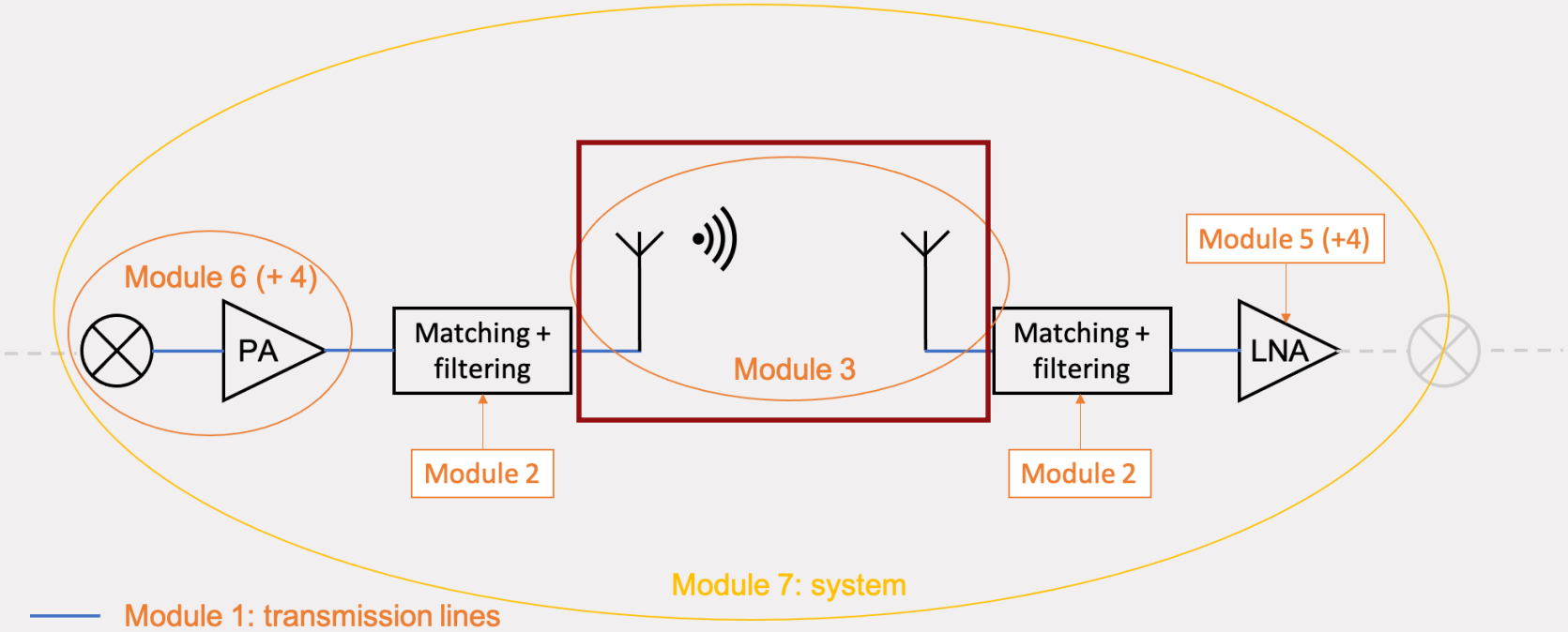
- We need passive networks for all sorts of things: matching, filtering, …
- Because of small wavelength, it matters *where* we put them and *how* we connect them together, how they are packaged
  - This gives us a lot of freedom!
- We can also create ‘equivalent’ components using transmission lines and stubs!

24 GHz LNA – passive elements



Why the ‘pie shape’?

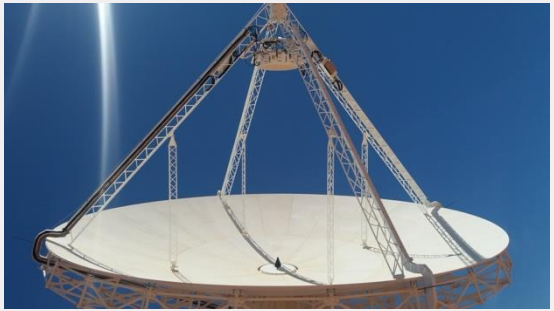
Module 3: Antennas



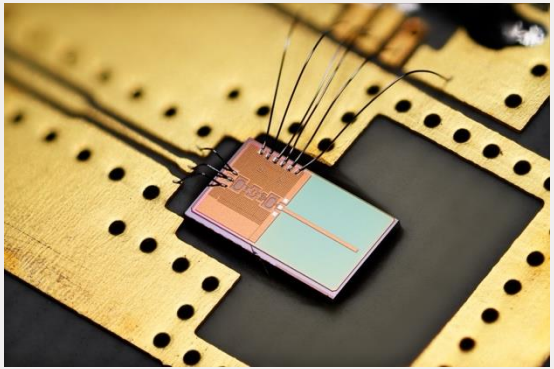
Module 3: Antennas

- How do we go from the ‘conducted world’ to wireless?
- We need something that:
  - Isn’t very lossy
  - Radiates very well
  - Is impedance matched
  - … + has a lot of other properties!

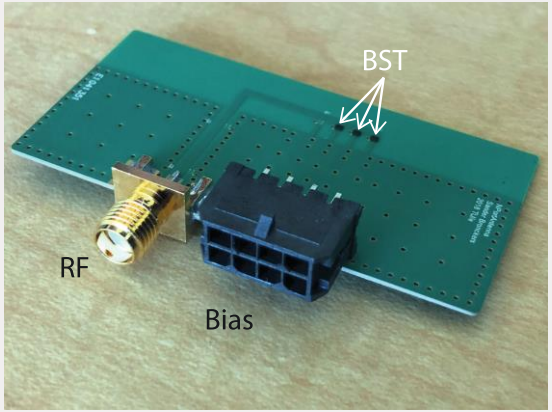
Module 3: Antennas – some examples



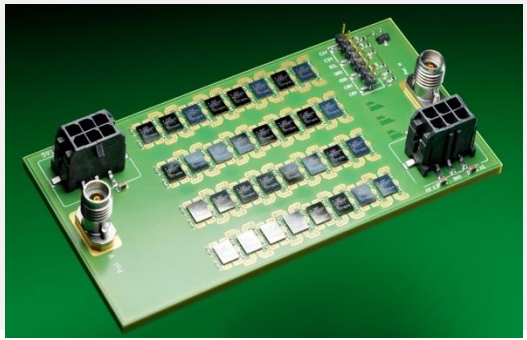
Reflector antenna for radio astronomy



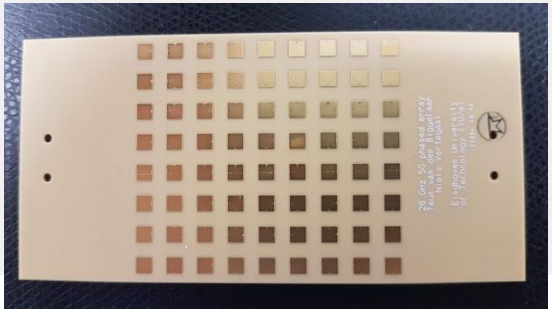
Bond-wire antenna (Johanssen et al.)



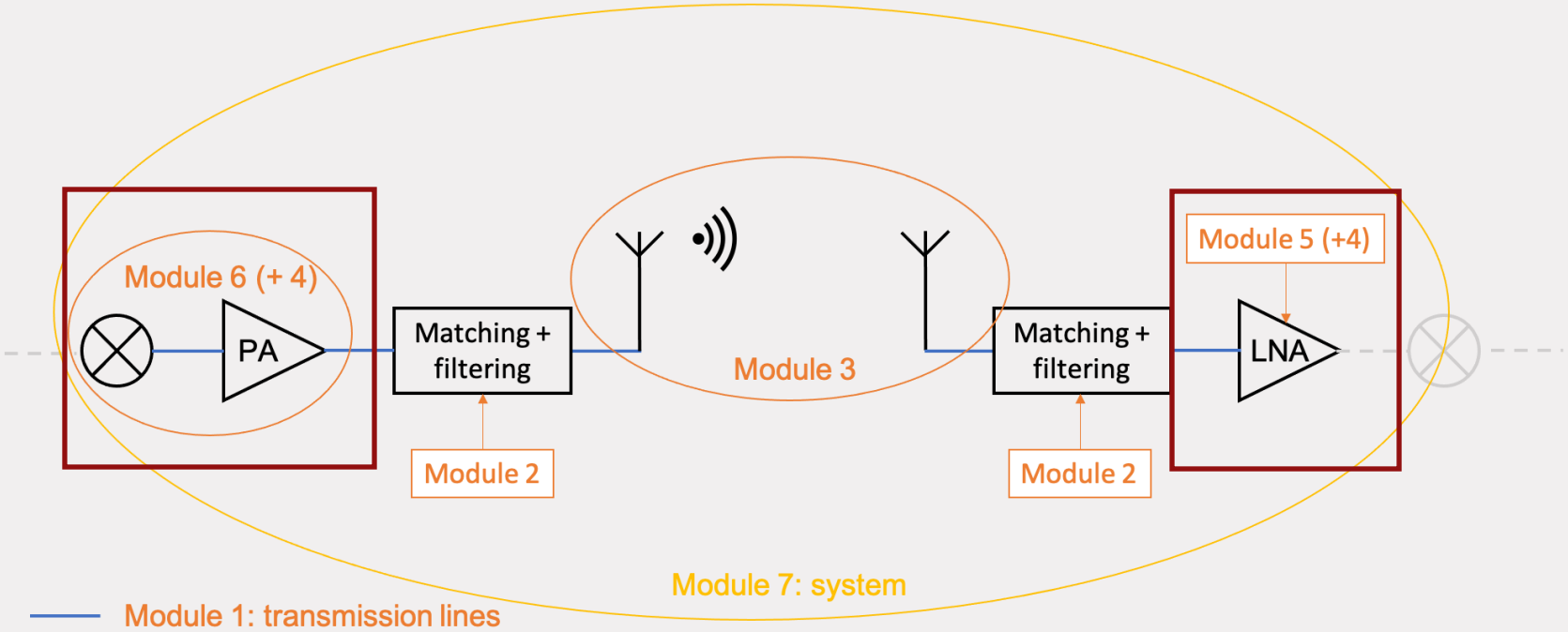
Frequency-reconfigurable antenna (Bronckers et al., 2019)



5G base-station patch array (Biggelaar et al.)



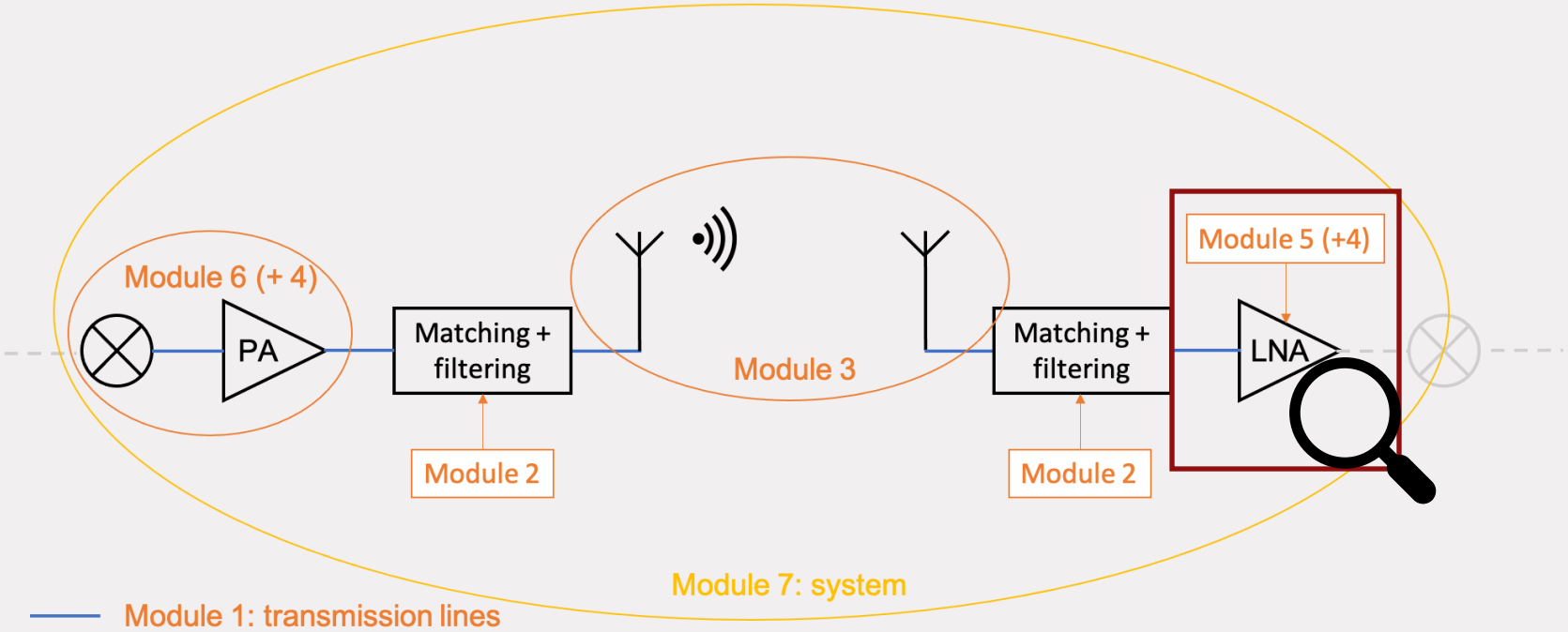
Module 4: RF Amplifiers



Module 4: RF amplifiers

- Nothing comes for free – amplification needed!
- How to make them efficient? How to make sure they don't oscillate?
  - Keep it simple! [That's already difficult enough...]
  - 'Common' aspects in module 4
- Two main pillars:
  - Module 5: Low-noise amplifiers (LNAs)
  - Module 6: Power amplifiers (PAs) and mixers

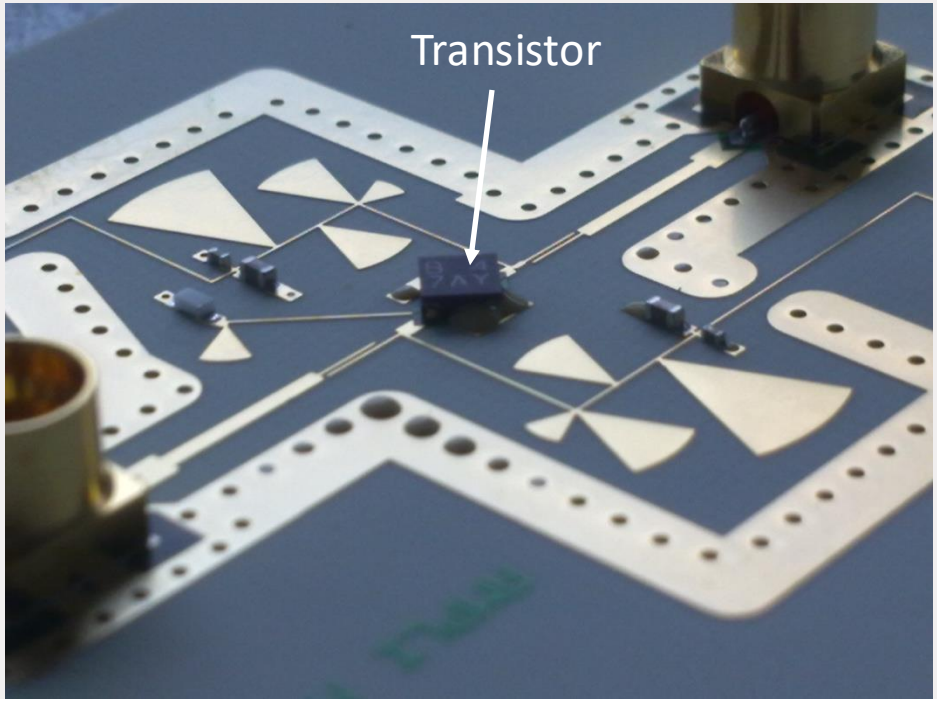
Module 5: LNAs



Module 5: LNAs

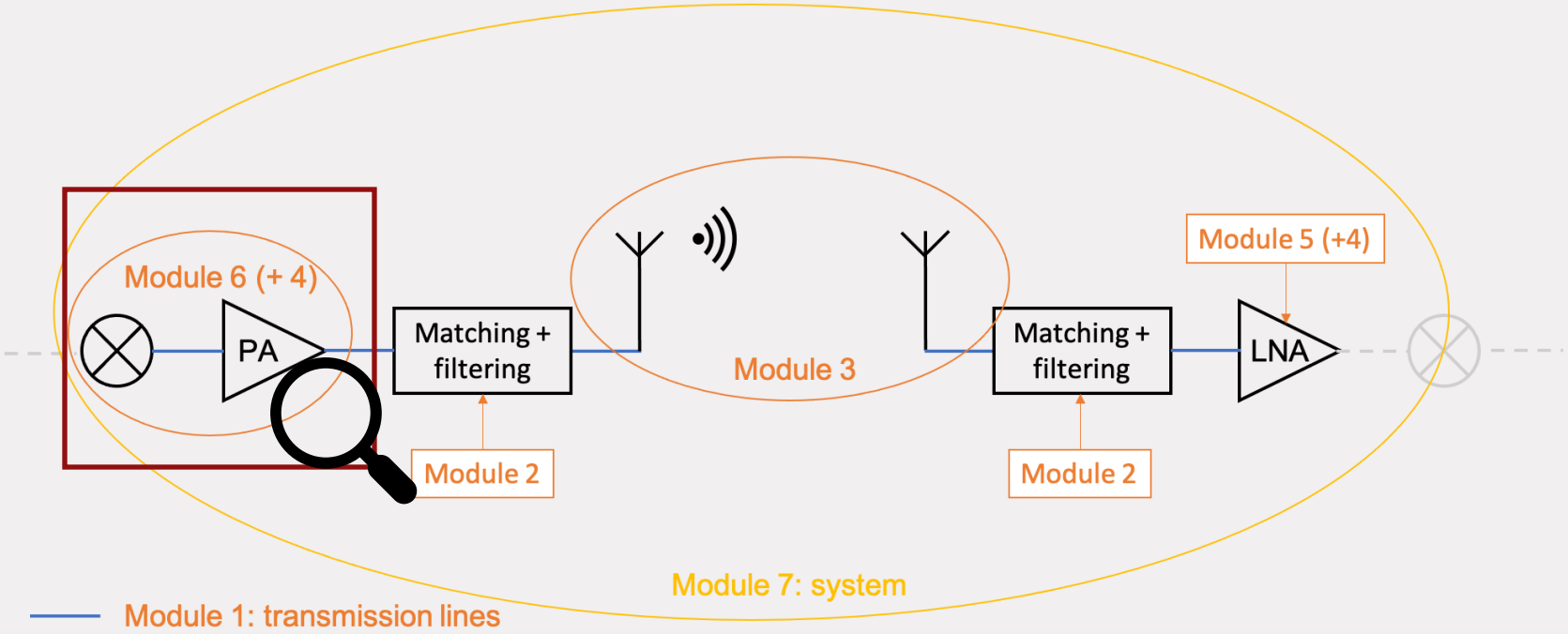
- Received power is very low
- Losses due to filtering, transmission lines etc. will make SNR even worse!
- → We need to find a way to ensure this doesn't happen
- Special amplifiers that have:
  - (Usually) low maximum input power
  - Very good noise performance
  - + a bunch of other criteria

24 GHz LNA



What's the rest for?

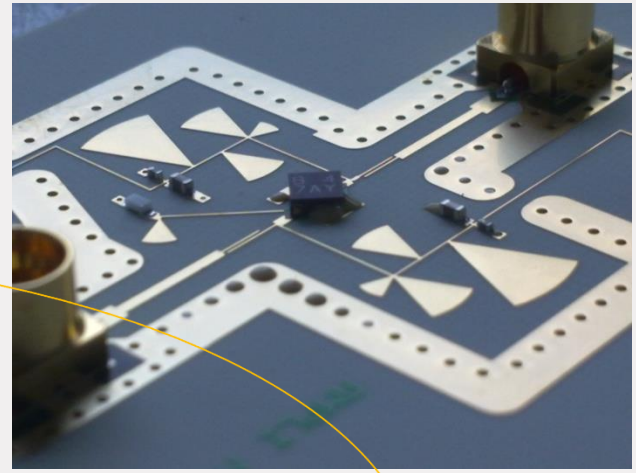
Module 6: PAs and Mixers

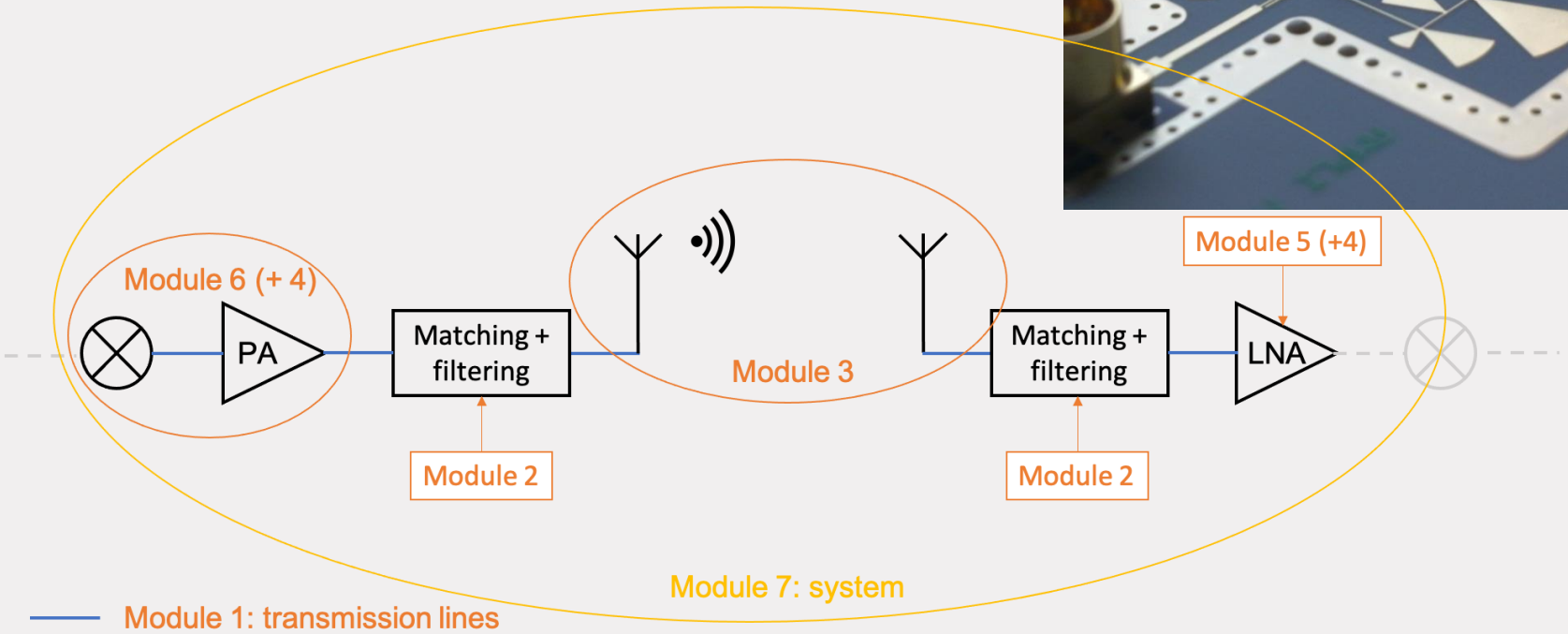


Module 6: PAs and Mixers

- We need to increase the output power of the transmitter
- Special amplifiers that have:
  - (Usually) high maximum output power
  - Noise performance not very critical
  - + a bunch of other criteria
- Can be combined with mixing
  - Frequency translation and amplification in one go

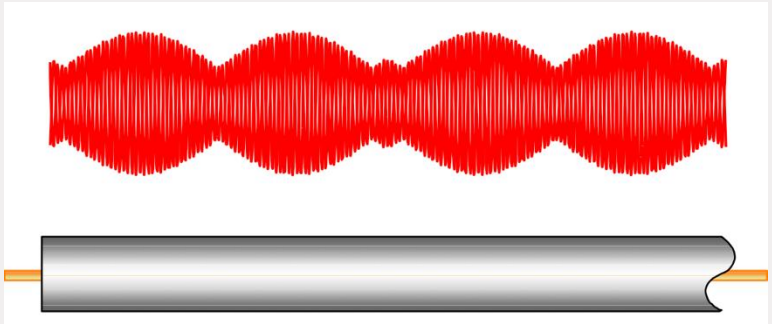
Back to our overview... Again!





A big problem…

- Voltage and current change over position! (and time)
- … And are difficult to use
- → What to measure?
  - S-parameters: related to reflection and transmission coefficients



Voltage on a coax, 'RF Power measurement basics,' Agilent, 2001

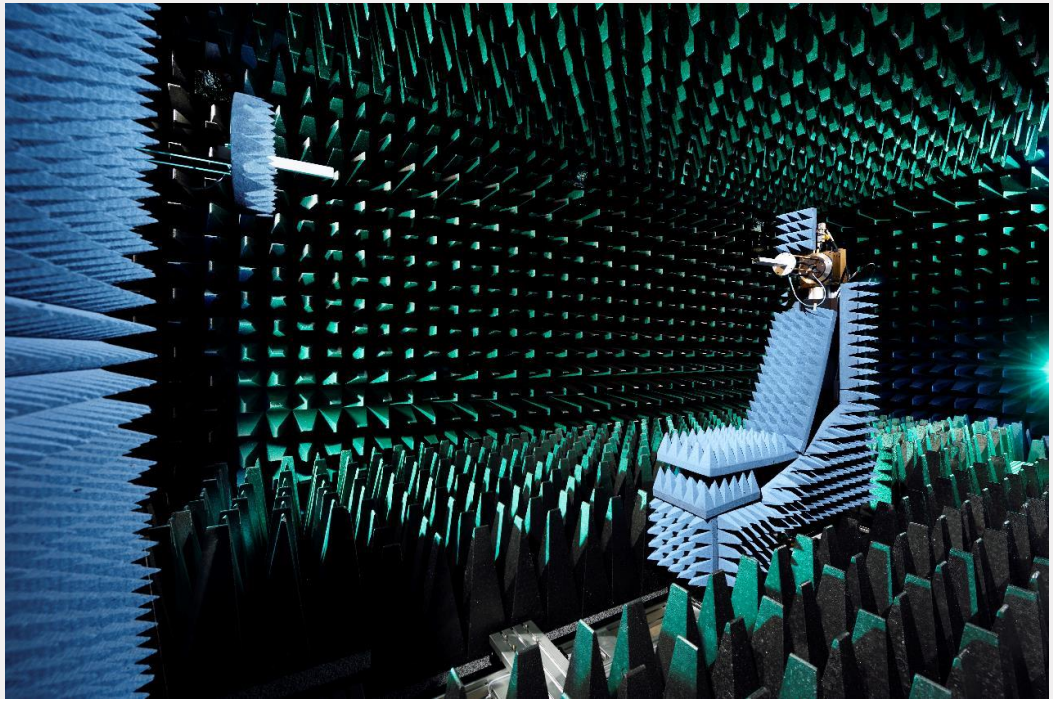
Labs: Get hands-on!

- Vector network analyzer: measure S-parameters

High-end VNA

VNA for 5XTC0

Antenna measurements

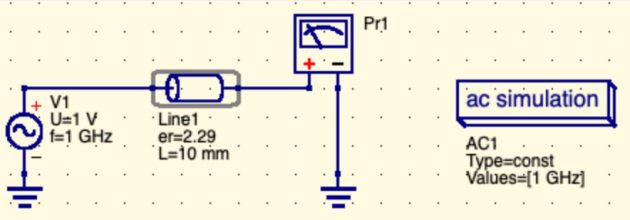


Some final reminders

- **Register** for a lab group tomorrow at the latest.
- You can find the **locations of sessions in the study guide**. Our main, leading document.
- Make sure to have fun with our practically oriented course!

Assignment

- Read the study guide. Take special note of locations!
- Install QUCS (only old versions available) or QUCS studio
- Configure a 1 GHz voltage source with coax line and voltage probe in AC simulation. Pick e.g. 1 GHz as a (constant) frequency.
- Look at the measured voltage.
- Change the length of the coax line. What happens? Why?



acfrequency	Pr1.v
1e9	1.05 / -0.00979°

- **Don't worry if you cannot finish!**